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HARVESTING RESIDUE FROM THINNINGS FOR USE AS AN ENERGY SOURCE

USDA Forest Service
Pacific Northwest Forest and Range Experiment Station
Portland, Oregon

FINAL REPORT TO
U.S. Department of Energy
Bonneville Power Administration
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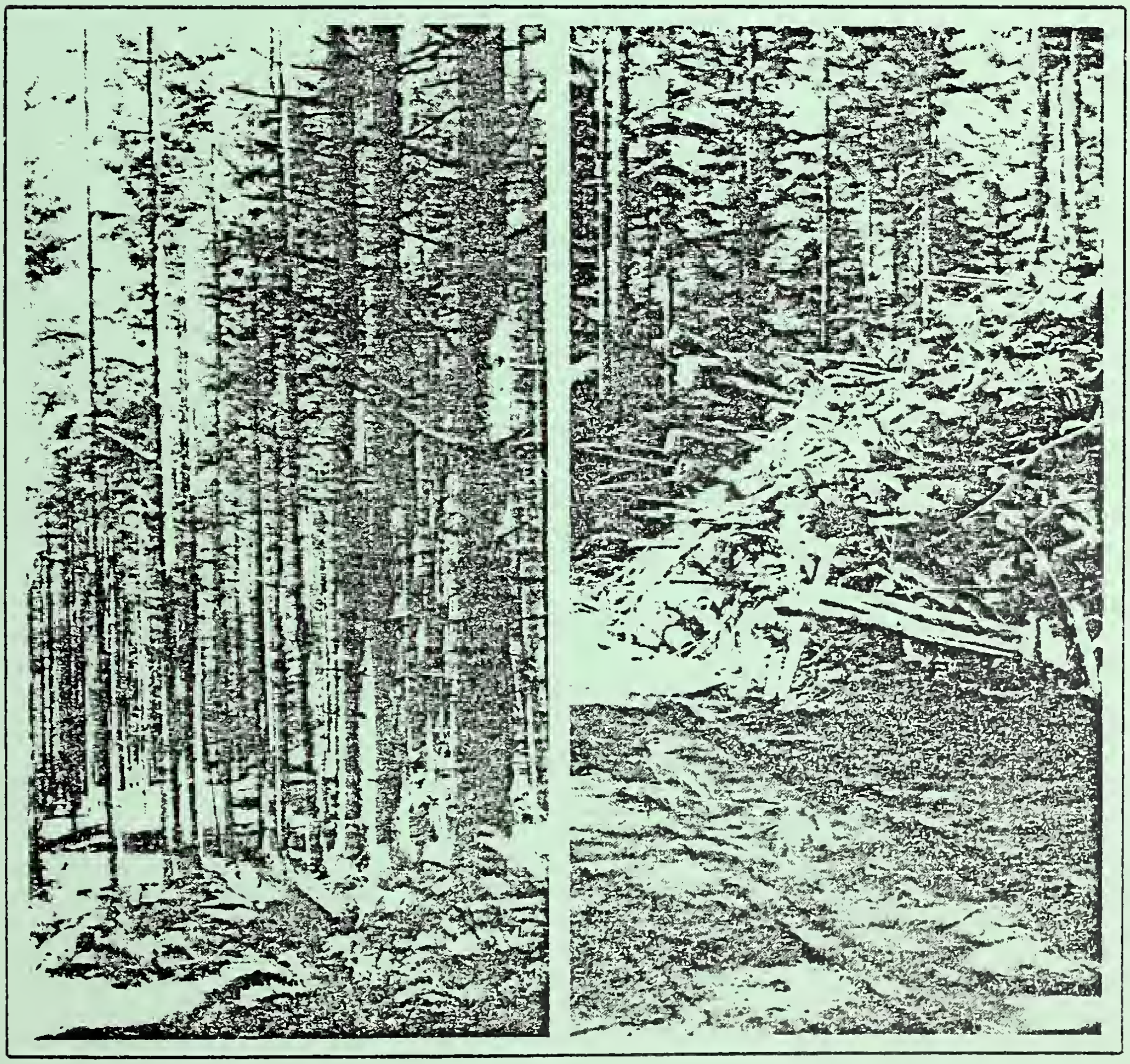

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ABSTRACT

Research quantified residue biomass concentrations after commercial thinning in young-growth Douglas-fir, determined the cost of cable yarding this residue, and defined the energy recoverable from it. Residue volumes were inventoried then yarded to landings within the study area. Thinning residue volumes averaged 1,059 cubic feet per acre. Residue piece size averaged 3.94 cubic feet. Residue yarding production averaged 320 cubic feet per hour. Costs of residue yarding, loading, and hauling averaged $0.24, $0.03, and $0.22 per cubic foot, respectively. Total residue value for energy use was about $0.20 per cubic foot. An electric utility's use of the residue as hogged fuel produced approximately 10,050 pounds of steam per 200 cubic-foot unit of chipped material.

Average stand volume of Douglas-fir before thinning was 3,635 cubic feet per acre. Thinning removed 64 percent of the Douglas-fir volume and 36 percent of the 250 Douglas-fir trees per acre.

Results can be used to assess feasibility of harvesting thinning residue for energy or products.

INTRODUCTION

Forest industries of the Pacific Northwest are looking more and more to young-growth timber stands for their wood supply. As these stands are thinned, a significant quantity of wood residue biomass is created, much of which could be utilized for energy or fiber products. To date, however, little information is available on potential quantities of thinning residues, or on the costs of harvesting these residues for utilization. The residue volume in thinned stands consists of tops and limbs, broken pieces, suppressed understory trees, cull logs left from previous harvests, and hardwoods.

Numerous researchers have determined and reported the residue concentrations that result from old-growth Douglas-fir and western hemlock clearcut harvests (Benson and Schlieter 1980; Bergvall and others 1978; Howard 1973, 1981a, 1981b; Johnson 1979; Townsend and others 1980). However, very little information is available on the residue loadings resulting from thinnings of young-growth unmanaged stands. This report presents the results of research to determine: (1) residue biomass concentrations following thinning in young-growth, (2) costs of cable logging this residue, and (3) the energy recovery possible.

DESCRIPTION OF THE OPERATION

The study was conducted in a 65-acre stand located within Oregon State University's Paul Dunn Experimental Forest, in Benton County, Oregon. The 35-year old timber stand consisted chiefly of Douglas-fir with some red alder and bigleaf maple. The stand volume of Douglas-fir before thinning averaged 3,635 cubic feet per acre based on volume estimates to a 4-inch top. Thinning removed 64 percent of the Douglas-fir volume and 36 percent of the 250 Douglas-fir trees per acre. Of the total volume removed (Douglas-fir volume plus residue biomass), 45 percent was classified as residue.

The research area was on relatively gentle terrain, with uphill slopes ranging from 10 to 20 percent. A sample of seven out of 36 skyline logging corridors were selected with slope yarding distances ranging from 300 to 650 feet (fig. 1). An existing spur road was utilized for access but did not contribute to residue volume. The residue material was yarded directly to the roadside. A minimal amount of road grading and widening was required.

The conifer thinning was conductd during the summer months. A year later the residue material was yarded, along with the remaining hardwood trees which were felled and bucked before yarding.

Total conifer thinning on the 15.85 acre site was 20,300 cubic feet (table 1). The residue volume harvested was 16,779 cubic feet. The average conifer tree harvested contained 13 cubic feet, had a diameter at breast height (d.b.h.) of 11 inches, and was bucked into two logs for yarding.

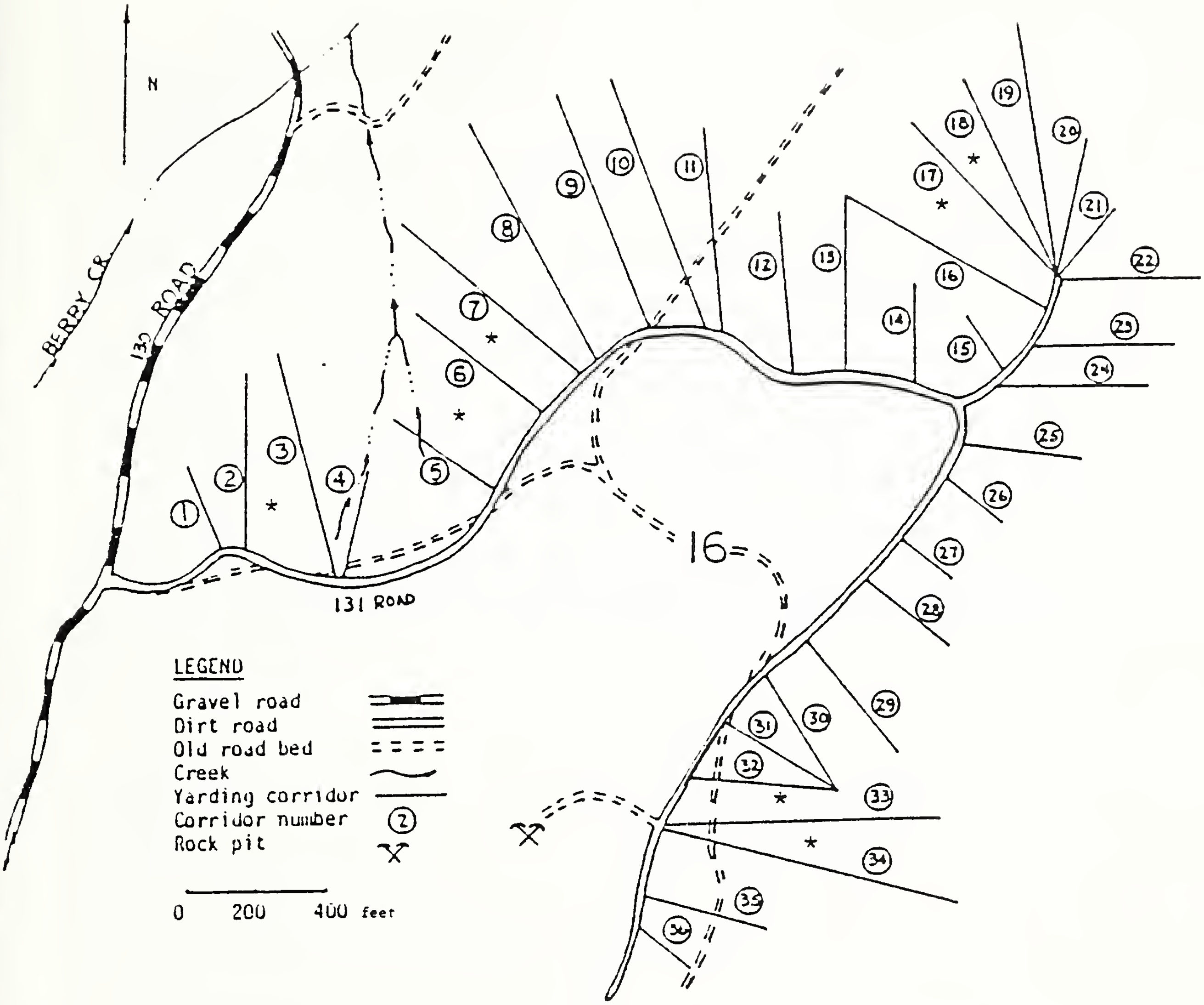

Figure 1.--Thinning residue study unit map, (*) denotes corridors (3, 6, 7, 17, 18, 33, and 34) logged in this experiment (map source, McIntire 1980).

An inventory of residue on the ground after the initial thinning operation found an average of 778 cubic feet per acre. Most of the pieces were in the 3.0- to 7.9-inch diameter class (table 2). This inventory was conducted by the Pacific Northwest Forest and Range Experiment Station, under direction of James O. Howard.

Table 1--Summary of merchantable and residue volumes logged from thinned Douglas-fir stand[1]

Skyline corridor number	Merchantable conifer removed	Residue removed	Area	Total merchantable conifer removed	Total residue removed	Total merchantable conifer and residue removed
	---Cubic feet per acre---		Acres	-----------------Cubic feet-----------------		
3	1,317	1,340	2.02	2,660	2,707	5,367
6	1,315	1,213	1.83	2,406	2,220	4,626
7	1,070	1,415	2.93	3,135	4,146	7,281
17	1,285	1,020	2.66	3,419	2,713	6,132
18	890	1,045	1.86	1,656	1,944	3,600
33	1,824	861	1.72	3,138	1,481	4,619
34	1,373	554	2.83	3,886	1,568	5,454
Total	--	--	15.85	20,300	16,779	36,079
Average	1,281	1,059	--	--	--	--

[1] Stand age is 32-38 years. Merchantable species composition is 90 percent Douglas-fir and 10 percent grand fir. Residue volumes include Douglas-fir and grand fir tops, maple, madrone, willow, oak, cherry, and cull logs from previous harvest.

Table 2--Inventory of logging residue after thinning

Small-end diameter class	Length in class feet				
	1-7.9	8-15.9	16-31.9	32+	Total
Inches	-----------Number of pieces per acre-----------				
3.0-7.9	21	42	73	26	162
8.0-11.9	3	3	5	3	14
12.0-15.9	0	1	2	1	4
16.0-19.9	0	0	1	0	1
20.0-23.9	0	0	1	0	1
Total	24	46	82	30	182

LOGGING METHOD

A gravity skyline system was used with a medium size Schield Bantam cable yarding machine equipped with a Maki carriage capable of lateral yarding within a distance up to 120 feet on each side of the skyline (figs. 2, 3). Three chokers were generally used for each turn of logs. The skyline system lifted the incoming ends of the logs off the ground but allowed the other ends to drag along the ground surface.

A Ramey truck-mounted hydraulic loader was used to deck logs, load trucks, and keep the landing area free from congestion.

The logging was done by Tree Farm Stewards, Inc., of Philomath, Oregon. The logging crew consisted of six persons. These included two persons setting chokers, two chasing (unhooking loads at the landing), one operating the yarder, and one serving as hooktender, or crew foreman. The hooktender doubled as the loader operator. Two chasers were required because residue pieces had to be bucked at the landing into lengths of 8 feet or less to facilitate the hauling operation.

The hauling contractor, Rexius By-Products Co., of Eugene, Oregon, used one truck to haul an average of two residue loads per day (fig. 4). The residue from three of the seven corridors was hauled to Eugene to be weighed, chipped, and burned in Eugene Water and Electric Board's (EWEB) industrial boiler. This amounted to 45 percent of the total residue harvested. Residue from the other corridors was sold as firewood to local woodcutters near Corvallis, Oregon, who were responsible for transporting their own wood. Volumes or weights of material removed were not recorded by individual woodcutters.

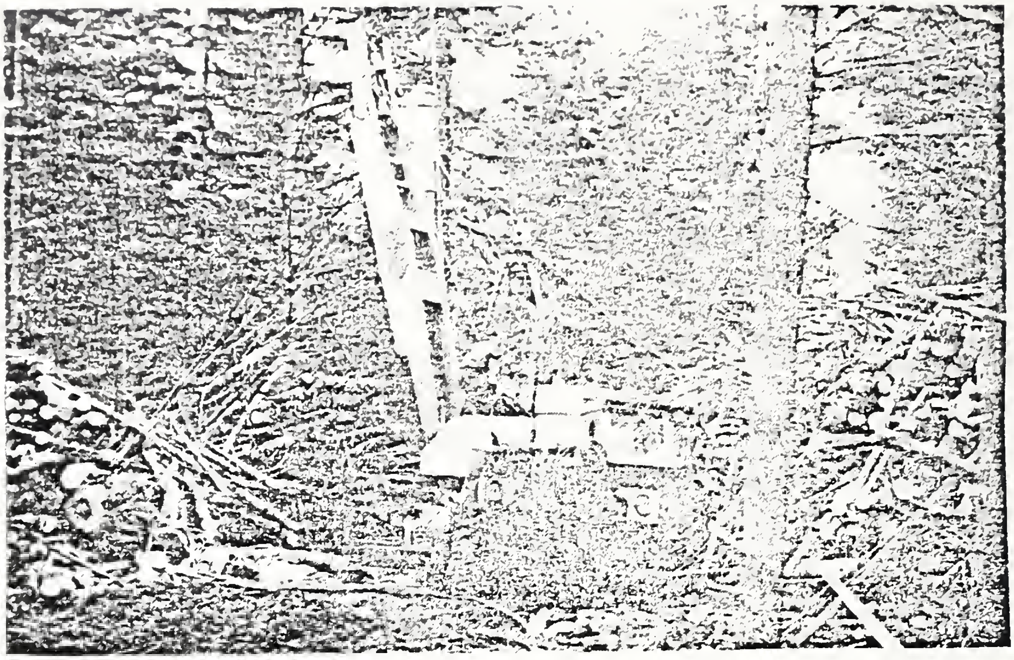

Figure 2.--Residue pile dwarfs Schield Bantam Yarder with a 35-foot tower.

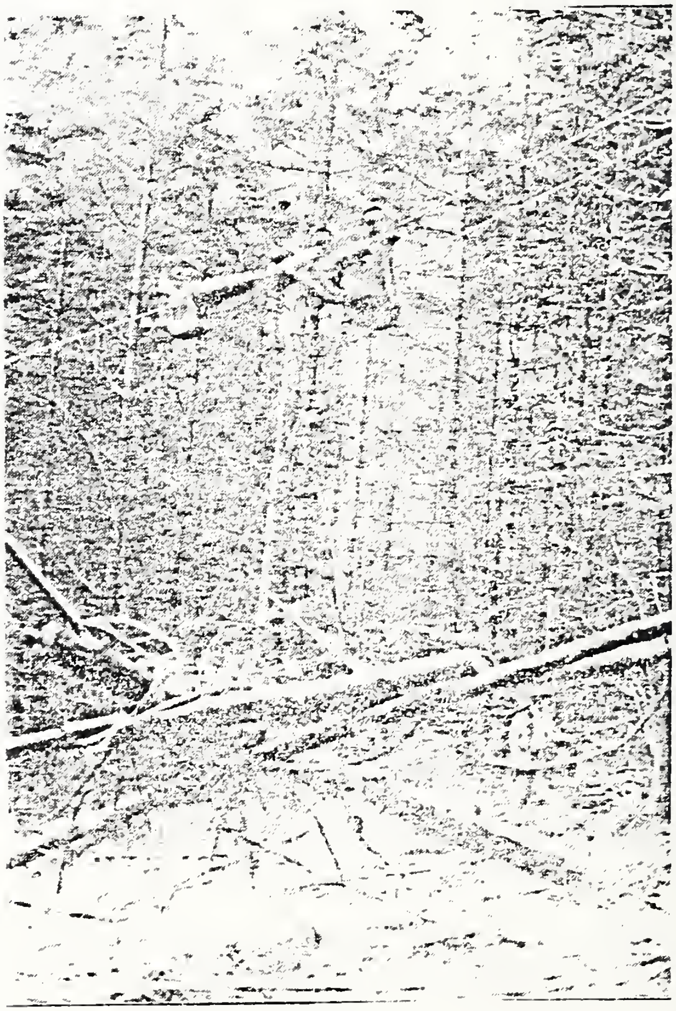

Figure 3.--Maki carriage with representative turn load. The stand in the background of carriage has not been thinned, it is outside the study area.

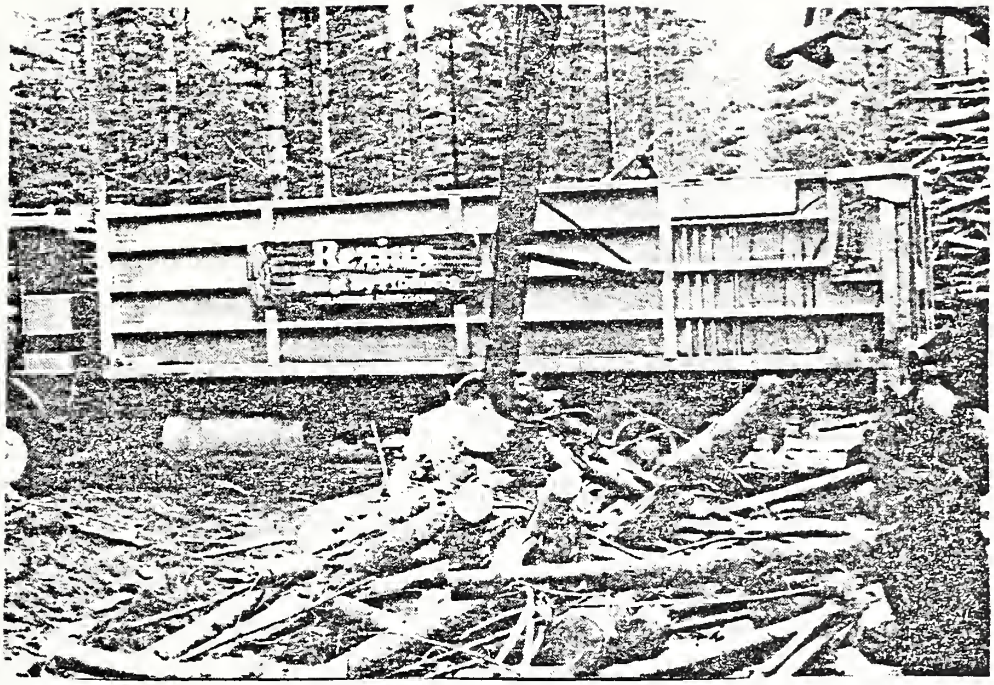

Figure 4.--Longbed truck that was used to haul residue to Eugene Water and Electric Board. Residue in foreground is representative of material removed from site.

YARDING TIME STUDY

Table 3 summarizes cycle production data from a 13-day time study. Time study data was recorded both at the landing and at the hooking site. The logs to be yarded during the study were coded by diameter and length class. The piece size (volume) distribution of residue removed is shown in fig. 5. Nonproductive delays consumed 15.6 percent of the productive time (fig. 6). Having the loader available to keep the landing area clean and to deck logs as they arrived at the landing helped reduce the amount of time consumed by delays.

Table 3--Average time of components in yarding cycle[1]

Component	Average time	Standard deviation	Proportion of total time
	Minutes		Percent
Outhaul	.30	.15	9
Lateral out	.28	.19	9
Hook	.72	.35	23
Lateral in	.26	.19	8
Inhaul	.56	.23	18
Unhook	.54	.26	17
Total without delay	2.66	.81	84
Average delay time	.49	.61	16
Total including delay	3.15	.77	100

[1] Sample size was 1,314 yarding cycles.

Multiple linear regression analysis was performed on the time study data to develop prediction equations for estimating cycle time excluding delays. A stepwise regression procedure was used to examine the effect of several variables on the various yarding time elements. Table 4 summarizes the statistical regression analysis of the yarding production cycle. The equations were chosen by comparing R^2 values and the level of significance of the variables. The variables selected are similar to those variables found useful when predicting production in most cable logging time studies (Aubuchon, 1982) and include slope yarding distance, lateral yarding distance, number of pieces per turn, turn volume, and percent sideslope.

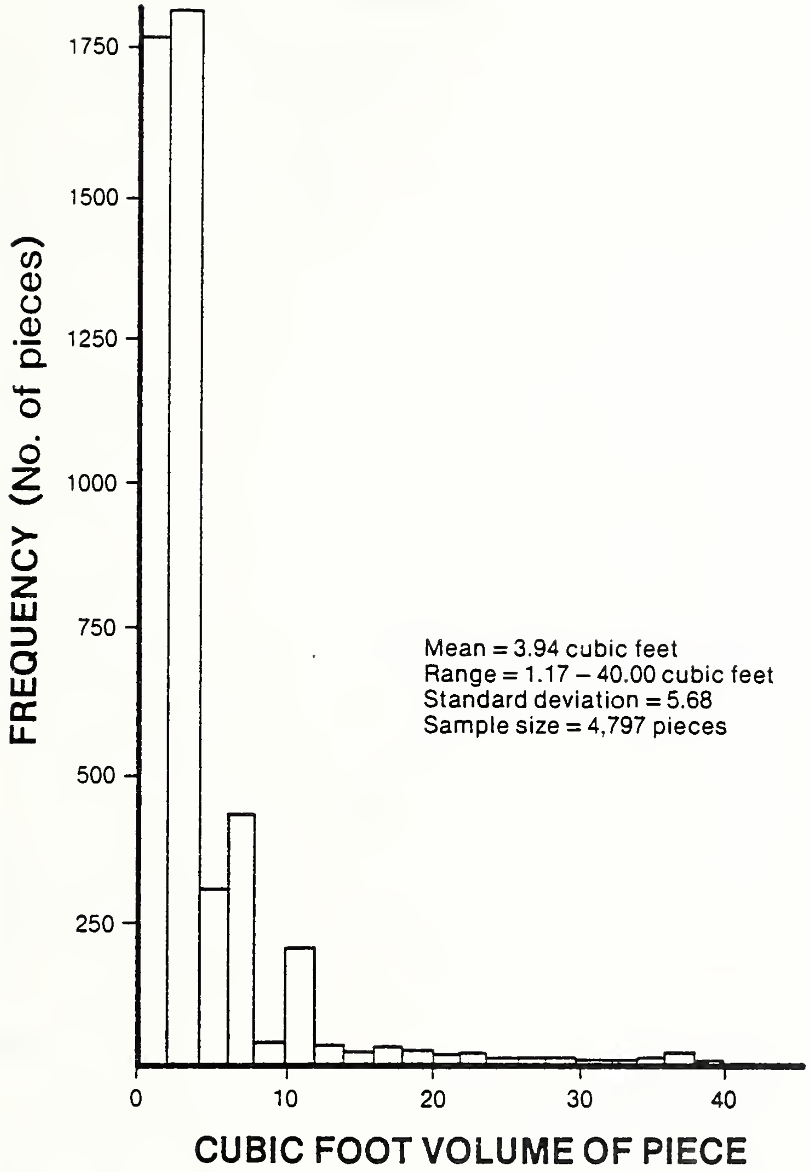

Figure 5.--Frequency distribution of residue piece volumes.

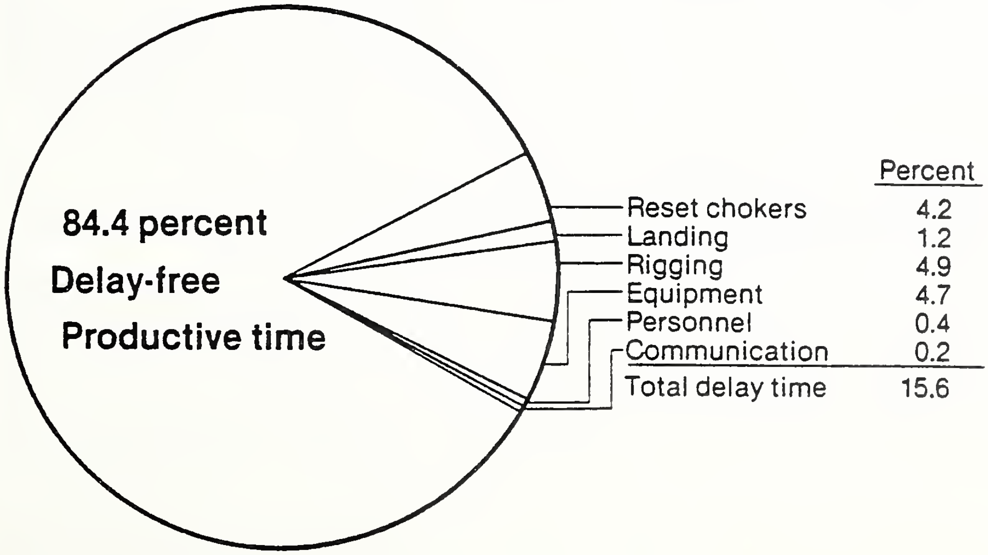

Figure 6.--Summary of delay times and percentages of total productive time.

TABLE 4--Predicting equations obtained by regression analysis, excluding delays (estimate of time in minutes)[1/]

Yarding component	Equation	R^2	N
Outhaul	y = .06764 + .00774 (X1) - .01605 (X2) + .01659 (X3)	0.65	1,320
Lateral out	y = .14007 + .001024 (X1) - .02974 (X2) + .05661 (X4)	0.52	1,320
Hook	y = .54454 + .02198 (X5) + .00725 (X6)	0.07	1,312
Lateral in	y = .14511 + .00436 (X4) - .00599 (X5) + .00258 (X7)	0.33	1,314
Inhaul	y = .15501 + .00121 (X1) + .00407 (X5) + .00471 (X7)	0.69	1.314
Unhook	y = .49447 + .00342 (X6)	0.02	1,314
Total cycle	y =1.61362 + .00229 (X1) - .01347 (X2) + .01184 (X4) + .01464 (X5) + .01502 (X6)	0.46	1.314

[1/] All coefficients significant at 5 percent level,
where X1 = slope yarding distance, feet
X2 = ground slope, percent
X3 = chordslope, percent
X4 = lateral distance, feet
X5 = number of logs per turn
X6 = turn volume, cubic feet
X7 = log volume, cubic feet
N = number of logged turns

Note: Ground slope is the average amount of slope perpendicular to a level contour.
Chordslope is a straight line between skyline support points.

RESIDUE LOGGING COSTS

Logging costs are summarized in table 5. Yarding, loading, and hauling costs are based on the total hours worked including both productive time and delay time. The costs do not include allowance for profit and risk.

The cost of yarding was calculated at $76.80 per hour, including costs of both the yarding machine and yarding crew. The yarder brought in an average of 320 cubic feet of residue per hour at a cost of $0.24 per cubic foot.

Loading cost was calculated at $38.40 per hour. Loading was accomplished at an average of 1,280 cubic feet of residue per hour for a cost of $0.03 per cubic foot.

The contract hauling cost averaged $0.22 per cubic foot. The hauling cost was high because of the distance and volumes involved. The residue had to be transported about 65 miles and the volume of residue hauled per truck load was relatively small, about 400 cubic feet of solid wood equivalent per load.

Total cost for logging and transporting the residue was $0.49 per cubic foot. In comparison the average value of the hogged fuel was $0.20 per cubic foot, not economically attractive at today's market prices. This comparison does not include, of course, any projected increase in the value of the residual stand due to the thinning release. A complete economic analysis would include that projection and also include a look at other potential uses for the residue volumes. Other products such as small sawlogs or pulpwood chips could have a higher value. Also, costs could probably be reduced by chipping in the forest rather than at Eugene.

TABLE 5--Summary of estimated costs of yarding, loading, and hauling residue[1]

Item	Cost
	Dollars per cubic foot
Yarding	$0.24
Loading	$0.03
Hauling	$0.22

[1] Based on hourly production rates of 320 cubic feet per hour yarding and 1,280 cubic feet per hour loading. Costs include depreciation, other fixed costs, and operating costs (fuel, oil and lubricants, maintenance and repair, crew, payroll taxes, and fringe benefits). Hauling cost based on haul distance of 65 miles one way.

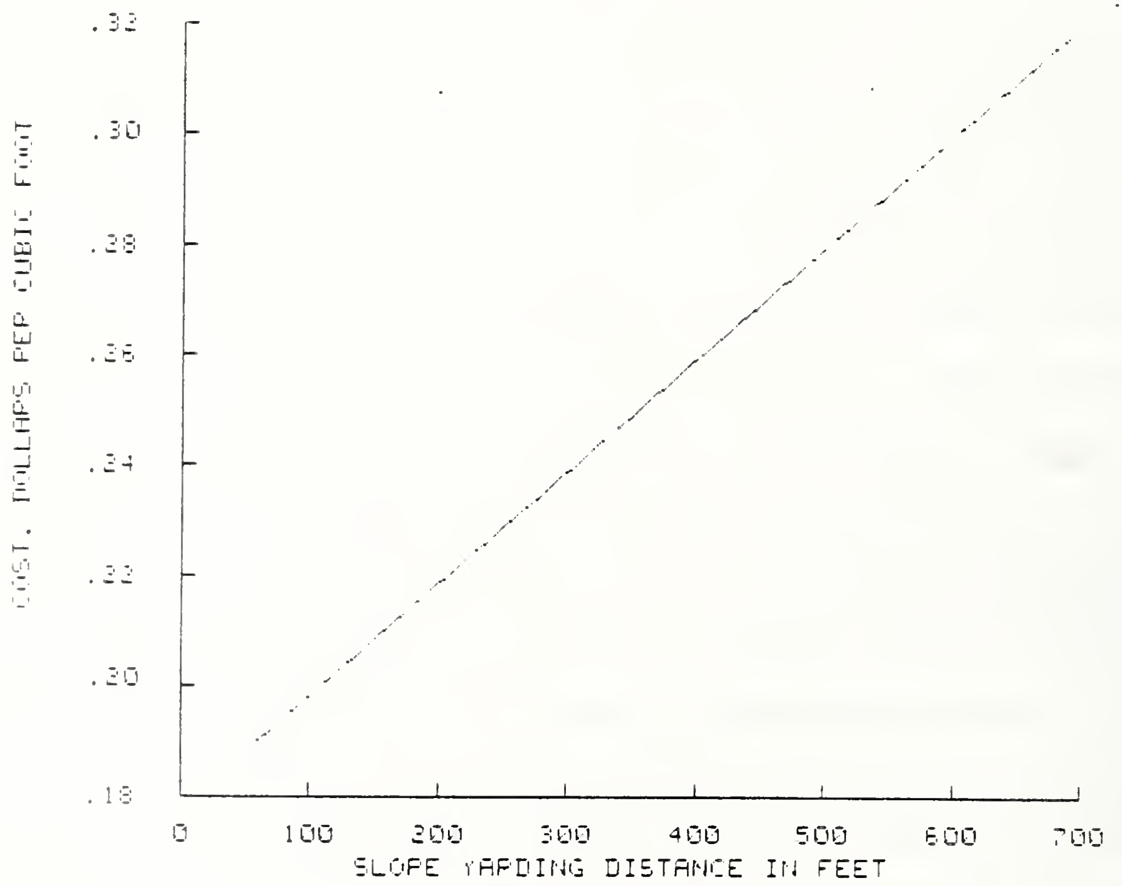

Figure 7.--Effect of slope yarding distance on yarding cost.

Many logging system analysts find that the sensitivity of individual variables (regression equation variables) with respect to cost per unit produced is more useful than single regression relationships. Accordingly, results for total cycle time from table 4 and cost data from table 5 were integrated and the results used to produce figures 7 through 11. Here, and in the examples that follow, all of the variables except one were in turn held constant at their observed mean value, allowing only the variable of interest to change.

Mean values were as follows:

Slope yarding distance	305.7 feet
Lateral yarding distance	30.1 feet
Number of pieces per turn	3.6
Turn volume	14.4 cubic feet
Ground slope	17.6 percent

Effect of yarding distance

Figure 7 shows the incremental cost per cubic foot for yarding residue at different slope yarding distances. In our first example, assume that a logging analyst is planning an operation for yarding residue biomass at slope yarding distances averaging 100 feet. This requires going out laterally from the skyline corridor an average of 30 feet to hook residue logs under conditions of average size turn, slope, and number of logs. The cost per cubic foot from the regression shown in figure 7 would be $0.198. The analyst now focuses on the incremental cost to extend the yarding distance an additional 100 feet to 200 feet. The cost to remove residue at 200 feet would be $0.218 per cubic foot. The cost of extending

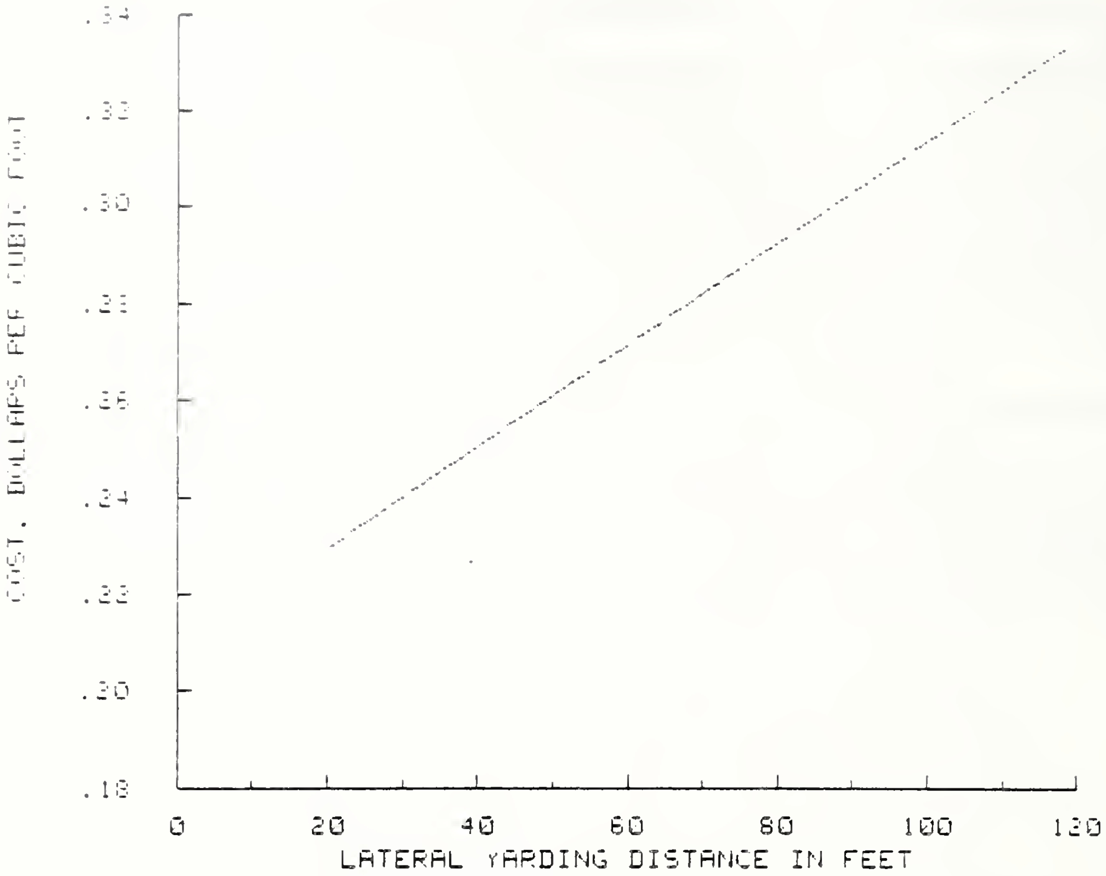

Figure 8.--Effect of lateral yarding distance on yarding cost.

yarding distance from 100 to 200 feet therefore increases by 10.1 percent. Now assume the analyst wishes to evaluate the incremental costs of increasing yarding distance from 400 to 500 feet. Going from 400 to 500 feet to remove residue would result in a 7.8 percent increase in cost per cubic foot, somewhat less than the increment between 100 and 200 feet.

Effect of lateral yarding distance

The incremental costs per cubic foot of going out laterally from the skyline corridor to hook residue logs can be determined similarly (fig. 8). For example, the cost per cubic foot to pull line out 20 feet would be $0.229. To go out another 20 feet to 40 feet would increase costs per unit by 9.2 percent to $0.250. Going out laterally from 100 to 120 feet would increase costs by 6.7 percent.

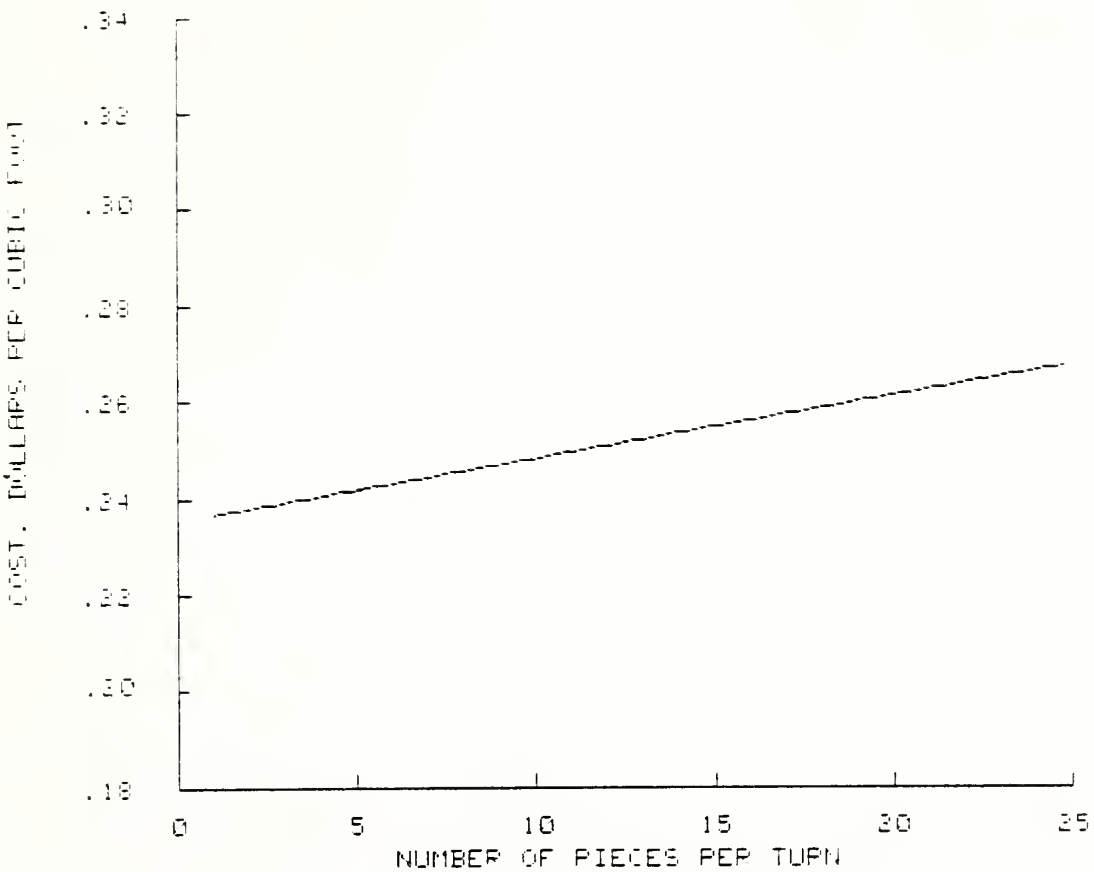

Figure 9.--Effect of number of pieces per turn on yarding cost.

Effect of number pieces per turn

The logging analyst may also wish to evaluate the cost of hooking and yarding different numbers of pieces per turn to develop the average 14.4 cubic foot turn. From the regression shown in figure 9, if one piece is hooked per turn, the cost per cubic foot is $0.236. If time is spent hooking more than one piece to make up the same turn size, for example three pieces, the cost increases by 1.3 percent to $0.239. If four pieces are hooked per turn at a cost of $0.240 per cubic foot, an increase to 10 pieces per turn to form the same volume turn would increase cost by 3.3 percent to $0.248. This type of analysis provides the analyst with information about the incremental cost per cubic foot to log residue in different piece-size combinations for a given turn size.

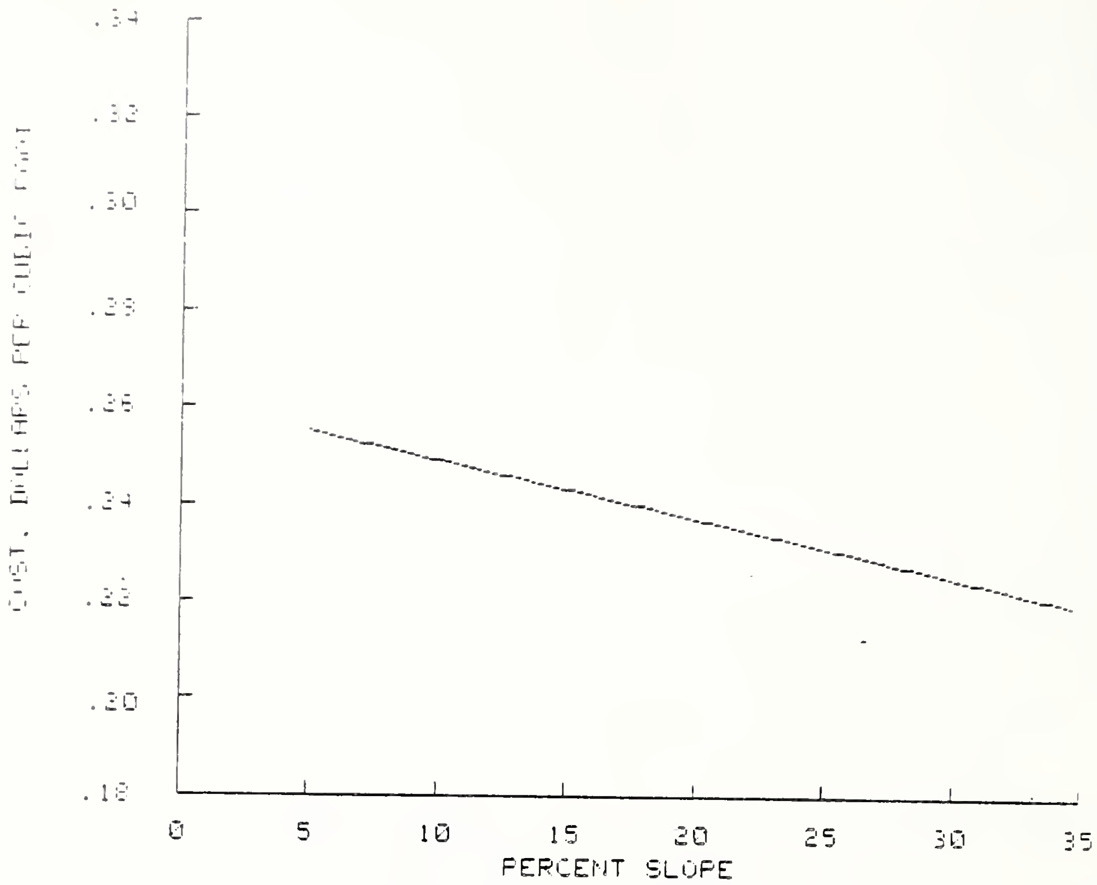

Figure 10.--Effect of percent slope on yarding cost.

Effect of percent ground slope

The analyst now looks at figure 10 to observe the effect of percent ground slope, or the average amount of slope perpendicular to a level contour. Here, the cost per cubic foot at 5 percent slope is $0.255. Going to a steeper slope of 15 percent decreases cost by 4.7 percent to $0.243. Remember, we are evaluating a system where the carriage returns to the back of the unit by gravity without the use of a haulback line. Steeper slopes allow the gravity system to function more efficiently. Going from 25 percent slope to 30 percent results in a 2.6 percent decrease in cost per cubic foot, which is less incremental change compared to the percent difference of going from 5 to 15 percent slope. Adequate slope is critical for gravity systems to work efficiently, but on excessively steep slopes the carriage speed as it returns to the back of

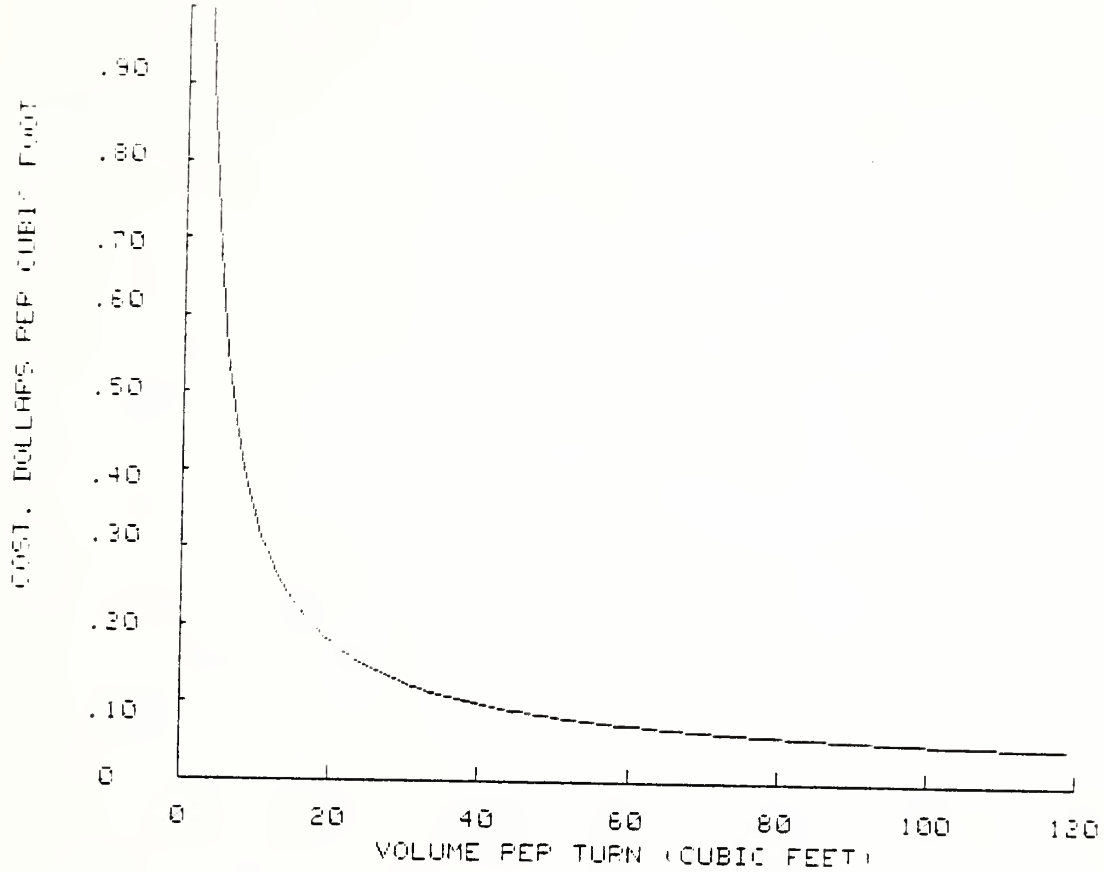

Figure 11.--Effect of volume per turn on yarding cost.

the unit is controlled by the yarder engineer, not the slope. This suggests to the logging analyst that a range of slopes exists for gravity systems within which individual slope values are equally efficient.

Effect of volume per turn

Of all the variables, volume per turn has the greatest effect on yarding cost per cubic foot (fig. 11). Sharply rising unit costs are experienced as turn volume is reduced below 40 cubic feet. For example, if all variables except turn volume are held constant at their mean value as observed in this study, a turn volume of 40 cubic feet would cost $0.10 per cubic foot. A turn volume of 20 cubic feet would cost $0.178 per cubic foot, and a turn of 10 cubic feet would cost $0.338 per cubic foot. Even more sharply rising costs occur below 10 cubic feet per turn.

Results from sensitivity analyses such as those shown in figures 7 through 11 should help the logging analyst understand the interaction among variables and how these variables affect cost of yarding residue thinnings by light cable systems.

ENERGY RECOVERY

Approximately 7,550 cubic foot of solid wood were transported to the Eugene Water and Electric Board (EWEB) for processing in their industrial boiler. In this trial, EWEB burned 95 units of wood residue material (200 cubic feet of hogged fuel per unit) in a direct-fired industrial steam boiler. The burn lasted 23 hours and provided 955,080 pounds of steam, or 10,053 pounds of steam per unit of fuel. This amounts to slightly over 50 pounds of steam per cubic foot of hogged residue. The hogged test fuel weighed 16 pounds per cubic foot at approximately 35 percent mositure content, total weight basis.

Some decision makers evaluate energy production on the basis of bone dry units of fuel rather than pounds of steam per unit (a bone dry unit of chips or hogged fuel equals 2,400 pounds of ovendry material). Accordingly, table 6 summarizes the results of the residue volume processed by EWEB on the basis of green weight, ovendry weight, ovendry tons per acre, and bone dry units per acre.

Table 6--Residue Amounts and Yarding costs[1/]

Corridor Number	Area	Residue amounts recovered: Ovendry tons (ODT)		Residue amounts recovered: Bone dry units (BDU)		Yarding Cost	
	Acres	Tons	Tons per acre	Units	Units per acre	Dollars per ODT	Dollars per BDU
17	2.66	36.00	13.53	30.00	11.28	$18.09	$21.17
18	1.86	36.76	19.76	30.64	16.47	12.96	15.22
33	1.72	20.15	11.72	16.69	9.76	17.64	21.17

1/ Data cover the three corridors from which residue material was hauled chipped and burned by Eugene Water and Electric Board. An ovendry ton is an equivalent weight of 2,000 pounds at zero moisture content. A bone dry unit (BDU) is specified as 2,400 pounds of oven-dry material. At 30 pounds per cubic foot a weighted averaged yarding cost of $15.96 per ODT equals $0.24 per cubic foot.

NET ENERGY BALANCE

A question arises as to whether an operation such as this might consume more energy than the energy value of the hogged fuel produced. The energy consumed in this operation was not measured directly, but the estimated ratio of energy output to energy input is 14.9 to 1 based on relationships described by Corder (1973) and Smith and Corcoran (1981):

			Million Btu
Energy output, study corridors 17, 18, and 33:			
185.829 overdry pounds x 8,800 Btu per pound =			1,635.3
Heat loss due to:			
35 percent moisture content, total weight basis	7 percent		
Formation of hydrogen in the fuel	8 percent		
Incomplete combustion	2 percent		
	17 percent		278.0
			1,357.3
Energy input:			
Yarding, 19.18 hours x 6 gallons fuel per hour =	115.1 gallons		
Loading, 4.80 hours x 5 gallons fuel per hour =	24.0 gallons		
		139.1 gallons	19.5
Hauling, 2,470 miles at 8 miles per gallon		308.8 gallons	43.2
Auxiliary management vehicles, 0.34 x yarding and loading consumption			6.6
Chipping, 0.43 x yarding and loading consumption			8.4
			77.7
Lubrication, 7 percent + indirect energy consumed in equipment manufacture and delivery, 10 percent = 17 percent			13.2
			90.9

Ratio: $\dfrac{\text{Energy input 90.9 million Btu's}}{\text{Energy output 1357.3 million Btu's}}$ = .067 or output ratio 14.9 to 1

CONCLUDING REMARKS

This study found that significant tonnages of residue exist in thinned stands and that such residue can be yarded with the same type of skyline equipment used in commercial thinning of young-growth Douglas-fir (LeDoux and Butler 1981).

As expected, the revenue from the hogged fuel product alone did not cover costs at 1981 market prices. However, the economic incentive for residue logging from thinnings will have to be determined on a case-by-case basis. Land management benefits and the potential for channeling some of the material into higher value products should be taken into account. When planning this type of operation consideration should also be given to the distribution of residue on the ground, any guidelines available on piece size distribution by slope yarding distance, and existing market conditions. The results summarized here are for a single field trial and specific logging equipment and wood markets. Other equipment or markets may significantly alter profitability of the operation.

This study has quantified the residue loadings in young-growth unmanaged stands, determined extraction costs using a medium sized cable yarder, and demonstrated energy recovery. Finally, the data obtained during this study will be valuable in planning future thinnings, and in analysis of prospective residue harvesting costs following such operations.

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